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REGULATORY GUIDE

OFFICE OF STANDARDS DEVELOPMENT

REGULATORY GUIDE 7.8

LOAD COMBINATIONS FOR THE STRUCTURAL ANALYSIS OF SHIPPING CASKS

A. INTRODUCTION

Appendix A, "Normal Conditions of Transport," and Appendix B, "Hypothetical Accident Conditions," of 10 CFR Part 71, "Packaging of Radioactive Material for Transport and Transportation of Radioactive Material Under Certain Conditions," describe normal conditions of transport and hypothetical accident conditions that produce thermal and mechanical loads that serve as the structural design bases for the packaging of radioactive material for transport.

However, initial conditions must be assumed before analyses can be performed to evaluate the response of structural systems to prescribed loads. This regulatory guide presents a set of initial conditions that is considered acceptable by the NRC staff for use in the structural analyses of type B packages used to transport irradiated nuclear fuel in the contiguous United States. The values in this set supplement the normal conditions and the hypothetical accident conditions of the regulations in forming a more complete basis from which structural integrity may be assessed.

B. DISCUSSION

To ensure safe structural behavior of shipping casks used to transport irradiated nuclear fuel, specific load conditions must be established that will encompass the static, dynamic, and thermal loadings that may be experienced by the casks during transport. This regulatory guide presents initial conditions that can be used in addition to parts of Appendices A and B of 10 CFR Part 71 to fully delineate thermal and mechanical load combinations for purposes of structural analysis. It is intended that this guide be used in conjunction with Regulatory Guide 7.6, "Stress Allowables for the Design of Shipping Cask Containment Vessels," for the analytic structural evaluation of the heavy (i.e., several tons in weight) casks used to transport irradiated nuclear fuel.

Regulatory Position C.1.a of this guide mentions environmental initial conditions. The external thermal environmental limits for which a shipping cask must be designed are stated in Appendix A of 10 CFR Part 71 as being 130°F (54°C) in direct sunlight and -40°F (-40°C) in shade. These limits are applied without any additional loading. For the other conditions of Appendix A and for the hypothetical accident conditions, this guide presents a range of ambient temperatures from -20°F (-29°C) to 100°F (38°C) as a part of the initial conditions. In the contiguous United States there is a 99.7 percent probability that any hourly temperature reading will fall within this range (Ref. 1). The insolation data provided in the International Atomic Energy Agency's safety standards (Ref. 2) have been adopted for this guide because they have sufficient conservatism when compared with other solar radiation data (Ref. 3).

Regulatory Position C.1.c mentions initial pressure conditions. It should be noted that the pressure inside the containment vessels and neutron shields of irradiated fuel shipping casks depends on several factors. These factors include pre-pressurization of the vessels, the cask temperature distributions associated with the ambient temperatures and the decay heat of the fuel rods, and any gas leakage from the nuclear fuel rods.

Regulatory Position C.1.e states that the values for initial conditions given in this guide are maximums or minimums. However, intermediate values could possibly create a more limiting case for some cask designs. For example, a seal design might be more susceptible to leakage at a pressure less than the maximum internal pressure, or a local structural response might be greater during an impact test if the weight of the contents was less than the maximum.

Appendices A and B of 10 CFR Part 71 outline requirements for packages used to transport type B quantities of radioactive materials. Some of these requirements do not pertain to irradiated fuel shipping casks, however, because of the heaviness of the casks or because the requirements are not structurally significant to cask design. Casks that are designed to transport one or more commercial fuel assemblies weigh many tons because of the large quantities of structural and shielding materials used. This massiveness causes a shipping cask to have a slow thermal response to sudden external temperature changes such as those that might be produced by quenching after a thermal exposure. The NRC staff feels that the water immersion test of Appendix B and the water spray test of Appendix A are not significant in the structural design of large casks. Therefore, they are not discussed in this guide. (Note, however, that these conditions may be significant to criticality and other nonstructural aspects of cask design.)

Similarly, the corner drop and the compression tests of Appendix A are not discussed because they pertain only to lightweight packages. The penetration test of Appendix A is not considered by the NRC staff to have structural significance for large shipping casks (except for unprotected valves and rupture disks) and will not be considered as a general requirement.

C. REGULATORY POSITION

The load conditions given here are considered acceptable to the NRC staff for use in the analytical structural evaluation of shipping casks used to transport type B quantities of irradiated nuclear fuels.

1. General Initial Conditions To Be Used for Both Normal and Hypothetical Accident Conditions

a. All initial cask temperature distributions should be considered to be at steady state. The normal and hypothetical accident conditions should be considered to have initial conditions of ambient temperature at -20°F (-29°C) with no insolation and of ambient temperature at 100°F (38°C) with the maximum insolation data given in Table 1. Exceptions to the above are made for the hot environment and cold environment normal conditions (which use other steady state values) and for the thermal accident condition (which considers the higher thermal initial condition but not the lower one).

b. The decay heat of the irradiated fuel should be considered as part of the initial conditions. Generally, the maximum amount of decay heat should be considered in combination with the thermal environmental conditions of Regulatory Position C.1.a. In addition, the free-drop and vibration parts of the normal conditions and the free-drop and puncture parts of the accident conditions should consider the case of no decay heat and the cask at -20°F (-29°C). These initial thermal conditions are summarized in Table 2.

c. The internal pressure used in evaluating normal and hypothetical accident conditions should be consistent with the other initial conditions that are being considered.

d. The release of all of the pressurized gases inside the fuel assemblies should be considered in determining the maximum containment vessel pressure.

e. It is the intent of this guide to specify discrete initial conditions that will serve as bounding cases for structural response. Maximum or minimum values of initial conditions are given. However, if a larger structural response is suspected for an initial condition that is not an extreme (e.g., an ambient temperature between -19°F (-28°C) and 99°F (37°C)), intermediate initial conditions should also be considered in the structural analysis.

2. Normal Conditions of Transport

Each of the following normal conditions of transport is to be applied separately to determine its effect on the fuel cask.

a. *Hot environment*—The cask should be structurally evaluated for an ambient temperature of 130°F (54°C) in still air and with maximum insolation (see Table 1). If the cask has auxiliary cooling systems for the containment or neutron shield fluids, these systems should be considered to be inoperable during the hot environment condition.

b. *Cold environment*—The cask should be evaluated for an ambient temperature of -40°F (-40°C) in still air and with no insolation. The case of maximum fuel heat load and maximum internal pressure should be considered in addition to the case of no internal heat load. The possibility and consequence of coolant freezing should also be considered.

c. *Minimum external pressure*—The cask should be evaluated for an atmopheric pressure 0.5 times the standard atmospheric pressure.

d. *Vibration and fatigue*—The cask should be evaluated for the shock and vibration environment normally incident to transport. This environment includes the quasi-steady vibratory motion produced by small excitations to the cask-vehicle system and also intermittent shock loads produced by coupling, switching, etc., in rail transport and by bumps, potholes, etc., in truck transport. Repeated pressurization loads and any other loads that may contribute to mechanical fatigue of the cask should be considered.

Factors that may contribute to thermal fatigue should also be considered. These factors should include the thermal transients encountered in the loading and unloading of irradiated nuclear fuel.

e. *Free drop*—The cask should be evaluated for a one-foot free drop onto a flat unyielding surface. The cask should contain the maximum weight of contents and should strike the impact surface in a position that is expected to inflict maximum damage.

3. Hypothetical Accident Conditions

The following hypothetical accident conditions are to be applied sequentially in the order indicated to determine the maximum cumulative effect.

a. *Free drop*—The cask should be evaluated for a free drop through a distance of 30 feet (9 meters) onto a flat unyielding horizontal surface. It should strike the surface in a position that is expected to inflict maximum damage and should contain the maximum weight of contents.

In determining which position causes maximum damage, the staff currently requests evaluations of drop orientations where the top and bottom ends, the top and bottom corners, and the sides are the cask impact areas. The center of gravity is usually considered to be directly above these impact areas. However, evaluations of oblique drop orientations are requested when appropriate.

b. *Puncture*—The cask should be evaluated for a free drop of 40 inches (1 meter) onto a stationary and vertical mild steel bar of 6 inches (15 cm) diameter with its top edge rounded to a radius of not more than 0.25 inch (6mm). The bar should be of such a length as to cause maximum damage to the cask. The cask should contain the maximum weight of contents and should hit the bar in a position that is expected to inflict maximum damage.

c. *Thermal*—The cask should be evaluated for a thermal condition in which the whole cask is exposed to a radiation environment of 1,475°F (800°C) with an emissivity coefficient of 0.9 for 30 minutes. The surface absorption coefficient of the cask should be considered to be 0.8. The structural response of the cask should be considered up to the time when the temperature distributions reach steady state. The possibility and consequence of the loss of fluid from the neutron shield tank should be considered for casks that use this design feature.

Table 2 summarizes the loading combinations given above.

D. IMPLEMENTATION

The purpose of this section is to provide information to applicants and licensees regarding the NRC staff's plans for using this regulatory guide.

This regulatory guide will be used by the staff after January 1, 1978, in assessing the structural adequacy of designs for irradiated fuel shipping casks with respect to the requirements in 10 CFR Part 71, §§71.35 and 71.36. Alternative methods that satisfy the requirements in the Commission's regulations will also be considered acceptable.

REFERENCES

1. M.B. Gens, *The Transportation and Handling Environment*, SC-DC-72-1386, Sandia Laboratories, Albuquerque, New Mexico, Sept. 1972.

2. International Atomic Energy Agency, Safety Series No. 6, *Regulations for the Safe Transport of Radioactive Materials*, 1973.

3. Department of the Army, *Research, Development, Test, and Evaluation of Material for Extreme Climatic Conditions*, AR 70-38, May 1969.

TABLE 1

MAXIMUM INSOLATION DATA

Form and location of surface	Insolation for 12 hours per day
Flat surfaces transported horizontally:	
Base	None
Other surfaces	800 $gcal/cm^2$ (2,950 Btu/ft^2)
Flat surfaces not transported horizontally:	
Each surface	200 $gcal/cm^2$ (737 Btu/ft^2)*
Curved surfaces	400 $gcal/cm^2$ (1,475 Btu/ft^2)*

*Alternatively, a sine function may be used, adopting an absorption coefficient and neglecting the effects of possible reflection from neighboring objects.

TABLE 2

SUMMARY OF LOAD COMBINATIONS FOR NORMAL AND HYPOTHETICAL ACCIDENT CONDITIONS OF TRANSPORT

Normal or accident condition	Applicable initial condition							
	Ambient temperature		Insolation		Decay heat		Max. internal pres.**	Max. wt. of contents
	100°F	-20°F	Max.*	0	Max.	0		
Normal conditions								
Hot environment - 130°F ambient temp.			x		x		x	
Cold environment -				x	x		x	
-40°F ambient temp.				x		x	x	
Minimum external pressure - 0.5 atm.	x		x		x		x	
		x		x	x		x	
Vibration & shock† -	x		x		x		x	
Normally incident to		x		x	x		x	
the mode of transport		x		x		x	x	
Free drop -	x		x		x		x	x
1 foot drop		x		x	x		x	x
		x		x		x	x	x
Accident conditions								
	x		x		x		x	x
Free drop -		x		x	x		x	x
30 foot drop		x		x		x	x	x
Puncture -	x		x		x		x	x
Drop onto bar		x		x	x		x	x
		x		x		x	x	x
Thermal†† - Fire accident	x		x		x		x	

*See Table 1.

**See Regulatory Position C.1.c and C.1.d.

†See Regulatory Position C.2.d for "Vibration and fatigue."

††Evaluations should be made 30 minutes after start of fire and at post-fire steady-state conditions.

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